CHAPTER 12

The Synthesis

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CONTENTS

12.1 THE SYNTHESIS

Agroecosystems are "human-managed" agricultural environments. In cutting forests, cultivating land, and growing crops, humans have immensely altered natural environments. Available resources in early settlements were intuitively utilized to secure food production. Climatic features, soil properties, and living organisms set the limits and restricted the range of human intervention. The innate regulation potential of agroecosystems remained a benchmark of farming skills in the long history of

agricultural evolution.[16,32] However, the intensive production methods of recent years are increasingly producing signs of serious disorders in agroecosystems. Excessive exploitation of natural resources, declining crop diversity, soil erosion, pollution of water and air, and vanishing wildlife are a few examples of problems associated with intensive agriculture.[40] Despite the tremendous achievements of modern agriculture in food security, the validity of former objectives for future developments in agriculture must be reconsidered.[53,54] Intensive farming technologies have been adopted without understanding the guiding principles of agroecosystems. Impacts of agriculture, particularly in the industrialized world, are no longer restricted to farming communities but implicate the entire society. The follow-up (external) costs for pesticide use in U.S. agriculture reportedly vary between \$1.3 and \$8.0 billion per year.[6,34,40,48] Soil erosion has been by far the biggest problem in agriculture. The annual cost of soil erosion for the UK public varies between £16.5 and £42.9 million per year.[40] Moreover, concerns attributed to agriculture have reached-global dimensions. Recent research, for instance, highlights close relationships between soil-cultivation methods and carbon losses and global warming (greenhouse effects).[7,16,20,40,41]

The impacts of intensive agriculture on the environment are mentioned not in order to devalue the achievements of modern research or to overstress the importance of ecological theory for future concepts in farming.[33,39] The aim is to outline areas perceived as signs of disturbance, instability, etc. (e.g., pollution and soil erosion). Sound proofs for relationships between species diversity and ecosystem stability[15,19] are still needed, although supporting research results are available.[2,5,11,18,29,35] Restricting the study scale[42] to soil may reveal better evidence for relations characterized by diversity and stability than are known from above-ground ecosystems. This assumption is strongly based on the immediate and direct effects of tillage on soil chemical and biological processes as well as on indirect long-term effects on the soil ecosystem. Likewise, alternating crop species affect the community structures of the rhizosphere and, consequently, associated organisms. The goal is to integrate more sustainable measures based on research results with farming system concepts. This is commonly acknowledged as the most promising concept for maintaining resources, minimize pollution, and ensure income.[3,38] No other farming measure may highlight this approach as clearly as soil management in agroecosystems. As the major medium for plant growth, soil is the basic resource for land use and development. Ecologically sustainable development is not feasible unless it includes the conservation of soil with its various functions. As soils are products of interactions between abiotic and biotic processes, conservation comprises physical, chemical, and biological features. This applies in particular to regulatory functions of soil biota in the formation of stable soil aggregates, the production and decomposition of organic matter, and population stability of the various soil-inhabiting organisms.

Interventions into soil structure, performed as cultivation or tillage, produce multiple effects on both tilled fields and surrounding environments. Within fields, tillage rearranges soil structure at varying intensity levels and accordingly affects soil physical, hydrological, chemical, and biological features. Soil tillage influences the production of organic matter above and below the soil surface as well as decomposition, mineralization, and the activity of soil biota. Soil-dwelling organisms show a wide range of responses to tillage. They may interact with the off-field ecosystems,

e.g., as food sources for species in adjacent hedgerows. On the other hand, tillage may exert serious impacts on the nearby environments. The off-farm effects related to runoff, erosion or pollution may be of serious concern for all society, in particular in erosion-vulnerable regions. This goes far beyond the farm scale to affect taxation and legislation. The views presented in this book on the impacts of soil management are based on scientific knowledge of the various effects of tillage on soil. A large set of criteria, including soil structure, gas exchange, water content, nutrient cycles, soil nutrient reserves, soil biota, seed germination, noxious and beneficial species, is covered. The impacts of soil-management systems on soil functions, species diversity, and environmental safety are guiding standards of evaluation—such systems must support the sustainability of soil production and maintain the innate potential of the soil to provide the basic functions of agroecosystems.

12.2 TILLAGE CONCEPTS

Soil management was and will remain an essential component of any farming system. This applies to traditional subsistence farming as much as to present and future agriculture. Because soil management is indispensable, it is essential to evaluate soil management systems for their long-term effects on potential soil to match established objectives. This is a fundamental feature of the paradigm of sustainability. By acknowledging that soil is not only the medium for growing crops but also the habitat for different organisms, water storage, purification, etc., crop yields can hardly be more than one among many other parameters for evaluating the functioning of soil ecosystems. Soil fertility,* soil formation, erosion, pollution potential, incidence of crop pests, diseases and weeds, and the abundance and diversity of natural enemies are other features of soil-management regimes. However, rigid standards or blueprints for appraisal of soil management cannot be established, and in addition they would not be desirable due to important differences between soils, sites and, crops etc. Only ecological principles may provide the common basis for appraising different management approaches.

Soil management is not necessarily restricted to cultivation, even though it is the most significant component. Crop rotation, organic residues, and cultivation pattern are a few among many other components that affect soil. In order to facilitate understanding, the following system of classifying tillage systems is suggested, based on their effects on surface residues. Three main tillage categories may cover all relevant tillage systems. These are:

- No-tillage (direct drilling) bans any other mechanical intervention into soil besides drilling furrows and leaving organic residues on the soil surface. Direct drilling is coupled with any no-tillage technique and the two terms are thus used synonymously.
- Noninversion tillage involves moderate intervention in soil structure. Different types of implements are used, ranging from shallow cultivation, mulching, and

* Defined as the innate capability of soil at a given site to yield without addition of purchased farm external inputs, is a second criteria to distinguish soil management systems.

ridging to combined deep tine and shallow cultivation. Organic residues are only partially worked into topsoil, leaving layers below in their positions.
- Plowing, in contrast to both of the two above-mentioned systems, turns soil layers upside down (conventional system), leaving no organic residue on the surface.

The distinct differentiation between systems allows for a distinct appraisal of tillage effects on soil as well as on different components of agroecosystems. The evaluation of effects is commonly dependent on the objectives that are targeted by the specific tillage concept. Because of this, there is wide variation in judgment of these three soil-management strategies. Farmers are likely to set up different priorities compared to nonfarming communities. Likewise, tillage impacts on agroecosystem functioning are perceived differently from those of the wider environment.

12.3 THE VARIATION OF TILLAGE EFFECTS

Appraisal of a soil-management system is highly dependent on the perception and viewpoint of the analyst. Tillage effects on nontarget species, for example, could hardly be more significant to a farmer than income. The hierarchy of objectives results in a decision regarding the tillage system of preference. The data reviewed in this book makes possible a presentation of the following views.

12.3.1 The Farmer's View

Farmers commonly choose and advocate tillage methods based on the feasibility of the technology, cost-effectiveness, and yields. Sometimes, pressing constraints of the farm, e.g., soil erosion, may influence a farmer's choice. A comparison of no-tillage, noninversion tillage, and conventional plowing highlights important aspects. The flourishing farm-machinery market is perceived as a reliable indicator of dissemination of tillage technology, despite regional differences.[43,47] Assuming that tractor power is available on the farm, implements of each of the three soil-management systems may be used. The limiting factor in this respect is unlikely to be technical feasibility but rather the cost of purchase. The most cost-effective system, in particular with regard to purchase and operational costs, may determine a farmer's decision. The operational costs for plowing, harrowing, and drilling have repeatedly proven to be higher than those of no-tillage, or the combined cultivation and drilling of noninversion tillage regimes (see Chapter 1 in this book). Compared to the plow, no-tillage produced the highest benefits even on the cropping-system level.[50] The savings achieved with conservation tillage are due to reductions in energy consumption and labor needs (see Figures 1.11 and 1.12).

12.3.2 Yield Potential

Yield responses to tillage systems can differ widely with respect to soil type, crop species, precipitation, and region. Accordingly, it is rather difficult to describe general trends on the effects of tillage systems on crop yields. Lal[26,27] reported lower yields under conservation tillage only for regions of high precipitation but not for

temperate or semiarid regions. These findings differ from yield data from some other high-precipitation areas. Crop yields of no-tillage treatments in tropical regions of Brazil were reported to be higher than those of plowed field,[4,9,28] whereas they were equal or slightly higher in Scotland.[44] Other long-term comparisons of tillage systems based on several crop species[10,14,25,49] and mainly in temperate zones showed no significant yield differences, either among tillage systems or in relation to crop species. Annual weather patterns proved to be more determinant for yield, rather than the soil tillage system. A review of studies on tillage systems failed to distinguish specific trends for any of the three soil-management systems related to yield potential, as long as other inputs remained comparable.

12.3.3 Soil Structure

The relationship between tillage intensity and soil erosion strongly advocates a reduction in cultivation intensity, especially at erosion-vulnerable sites. The no-tillage system provided, in combination with cover crops, the most effective erosion control, followed by noninversion tillage techniques.[31,47] Banning cultivation enhances water-infiltration rates, yielding a cutback of surface runoff and nutrient leaching from the soil and an increase in preferential fluxes. The efficiency of these mechanisms in erosion control is repeatedly observed in the different world climatic zones (see Chapter 2 and Reference 31). Based on these results, there is no justification for ignoring this soil-management potential at erosion-vulnerable locations, e.g., sloping sites.

Since soil physical features influence diversity and abundance of soil biota, tillage impacts on soil structure potentially have further implications for soil-inhabiting organisms. This is due to different effects of tillage. Soil structure, for example, produces significant effects on the soil–air interface, aeration, water infiltration, runoff, erosion, and plant roots. In the short term, tillage systems change soil porosity, aeration, homogeneity of organic-matter distribution, and structural habitat features. In the long term, conservation tillage contributes to the accumulation of crop residues/organic matter in topsoil and in this way to the improvement of both environmental and feeding conditions of topsoil-dwelling species. Apart from this effect, various other physical parameters were enhanced as conservation tillage systems were put into place, including aggregate size/distribution, soil water content, infiltration, etc. On the other hand, some of these advantages may even have negative implications. The facilitated preferential flow in no-till soils may contribute to a nitrate-leaching risk. In contrast, homogenization of the topsoil by plowing may decrease preferential flow and consequently limit risk. Nitrate leaching is, however, not a function of the tillage system alone but depends on the whole concept of soil management including cover crops and tillage-based adjustment of fertilizer supply. Simply, it requires a comprehensive farming system approach.[13,51,52] The leaching behavior of pesticides under no-tillage and noninversion-tillage regimes differs from that of nitrates. The concentration of organic matter in topsoil, the associated enhanced microbial activities, and the active ingredient applied significantly contribute to enhance degradation and to minimizing pesticide residues in soil leachates under conservation tillage.[30,50]

12.3.4 Nutrient Availability

Cultivation induces changes in soil moisture, gas and organic-matter distribution, and mineralization, yielding distinct effects on nutrient availability in soil solution. Both short- and long-term effects can be related to the tillage system. Single tillage operations tended to accelerate mineralization of soil organic matter depending on weather conditions. In contrast to conservation tillage, mineralization processes in plowed soils tend to "flash-up," making a large amount of nutrients available in soil solution independent of crop uptake. This phenomenon is lacking or rather weak under no-tillage and noninversion-tillage treatments. In the long term, however, no- or reduced tillage can be as productive in mineralization as a plowing system. Increased soil organic-matter content under conservation soil-management systems compensate for a lower net mineralization, to be in total as high as that of conventionally plowed soils, but over a longer period of time. Both conservation tillage systems tend to raise soil nutrient reserves, providing grown crops with a higher proportion of required nutrition from organic-matter stocks. This is likely to match better the long-term objective of maintaining soil fertility.

12.3.5 Responses of Soil Biota

Worldwide investigations on tillage impacts on soil biota reveal that soil biota respond in different ways to soil tillage regimes. Several crop species, soil types, climatic zones, and organisms were considered. In the overall context, microphytes and earthworms showed broadly consistent responses to tillage systems, followed by other biota. Due to their manifold role in agroecosystems, responses of earthworms to tillage regimes may have various implications. The impacts of earthworms upon agroecosystems and their reactions to management inputs appear to be less specific than once thought since earthworm behavior and its overall effects may change with habitat, cropping, and earthworm growth stage. Earthworms in arable cropping systems are adversely affected by increasing soil tillage intensity. In various studies, highest abundance and biomass were reported in no-tillage soil, in particular with cover crops, followed by noninversion-tillage treatments. In contrast, plowed soils hosted the lowest worm populations, regardless of the crop grown. Crop species, manure amendments, cover crops, and toxicant bans are reported as further measures for supporting earthworm populations. A large number of the documented soil structural improvements resulting from conservation tillage are attributed to earthworm activity. Like earthworms, enchytraeid worms respond positively to declining intensity of soil cultivation. However, these minute animals are more affected by organic-matter supply and moisture than by tillage alone.[8]

Although less significant for soil structural formation, other soil invertebrates are indispensable for the functioning of terrestrial ecosystems. Their responses to soil tillage differ due to the presence of other species and their phenology, site conditions, soil type, crops grown and, organic amendments among other farming practices. This again underlines the significance of the components of associated farming systems. The porosity shifts due to tillage, for example, exert selective pressure on euedaphic arthropods based on their body size. On the other hand, tillage

effects on soil moisture determine dominance and diversity of some other faunal groups, e.g., nematodes. Similarly, burial of organic residues by plowing imposes adverse effects on surface-dwelling (epigeal) animals. The reduced access to food sources forces species to expend more energy in search for food, at the cost of their reproduction, with adverse effects on population dynamics of the species. No- and noninversion tillage concepts result in substantial proportions of organic residues remaining on the soil surface, accessible to epigeal faunal groups. In such a food-rich environment, populations of surface dwellers are likely to be enhanced. Unlike soil inhabitants, epigeal predatory arthropods, which feed mostly on the abundant pests, show higher adaptation to land cultivation. However, responses of individual species to soil disturbance differ widely. Due to species phenology, tillage method, and number, frequency, and timing of operations, various responses to tillage system are reported. Different species' reactions to soil and other crop-management practices were reported for Carabidae, Staphylinidae, Araneae, and other taxa (other soil-dwelling taxa are not covered in this book). In general, both abundance and diversity tend to increase as tillage intensity is reduced.

12.3.6 Tillage and Trophic Interactions

Unlike primary consumers in soil nutritional webs, animals of higher trophic levels commonly respond indirectly to tillage regimes. Shifts in densities of prey species result in responses of species feeding on them. Increases in densities of soil microphytes are followed by increasing populations of grazing species. Similarly, fungivores and bacterial feeders respond to augmentation of bacterial and fungal colonies. The tillage effect in such cases is a result of changing soil environment but is strongly influenced by other farming components. The latter factors may even overrule the effect of tillage. Plant-parasitic nematodes provide a good example in this context. Crop species or crop rotation are acknowledged to affect endoparasitic nematodes more than tillage. This has been repeatedly documented, e.g., for soybean and potato cyst nematode. Even crop variety may determine the size of the subsequent population of some species. However, free-living nematodes, including the predatory Mononchidae, tend to respond differently to soil management. Some free-living plant-parasitic nematodes are reported to be suppressed under reduced- and no-tillage conditions, whereas nematodes of other feeding habits differ in their reactions to tillage. Nematodes in general seem to respond to environmental changes caused by tillage since community structures of nematodes are largely affected by soil texture and moisture. Populations of omnivores and predacious nematodes increased remarkably as tillage intensity declined.

Like nematodes, the diversity and population size of phytophagous Diptera are mostly determined by the crop and its associated soil conditions. Dipterous larvae are naturally concentrated in topsoil. This is likely to facilitate the emergence of adults from soil. This distribution pattern reverts to its opposite after plowing. The tillage effect in this case seems to be initially of pure mechanical nature. However, consequent changes in soil environmental features, in particular of moisture and organic-matter distribution, may induce higher impacts on Diptera than tillage type.

Soil-inhabiting arthropods showed more or less specific tillage responses. This may be attributed to the advanced organization of mesostigmatic mites and Collembola—the two groups addressed in this book—in soil ecosystems. Plowing revealed population declines in the majority of the studies reviewed. As a general trend, species diversity and abundance were, with few exceptions, enhanced with reduced tillage intensity. Careful integration of supporting measures, e.g., cover crops, organic amendments, and avoidance of toxicant inputs, is acknowledged to be of key significance for these microarthropods.

Thus, abundance and diversity of soil fauna are likely to increase as tillage intensity declines. The range of responses differed between the taxonomic (nematodes, Collembola, mesostigmatic Acarina, and dipterous larvae) and functional groups. Increases in species number of a given taxon may indicate shifts towards a site-specific "steady state" related to species richness. This is the case if the enhancements remain consistent over time and across crop species.

12.3.7 Seed-Germination Patterns

Seeds in arable soil environments may be affected by cultivation practices. Tillage effects involve sown crop and weed seeds. Tillage-related shifts in structural arrangements have consequences for the germination behavior of the species involved. Seeds placed in subsoil layers are likely to persist longer. Even shallow seed incorporation resulted in reduced seed germination of sunflower.[36] The burial of weed (including volunteer) seeds by plowing into soil produces mechanical and biological effects. The operation imposes dormancy on seeds in deeper soil layers. Dormant seeds remain "conserved" until subsequent plowing. Under these conditions they are not affected by the mortality factors operating on soil surface, including weed control. In contrast, seeds in shallow positions are likely to germinate faster and in greater numbers.[36,45] The distinct germination patterns of weed seeds explain why tillage systems differ widely with regard to germinated weed densities. Different germination patterns are described for weed species independent of location in the soil profile. Shifts in weed communities reflect the fitness of the weed species to survive in soil environments shaped by tillage. Grass weeds, both annual and perennial, for example, tend to be more adapted to no- and noninversion-tillage soil conditions than to plowing. Blackgrass has proved to be associated with low tillage intensity. In contrast, broad-leaved species showed no consistent trend or were of lower density under minimal soil tillage regimes. Despite the observed preferences for specific soil environment, long-term tillage effects were largely dependent on the complementary measures of the farming system, in particular with regard to crop rotation, cover crop, fallow management, fertilization strategy, and weed control. As long as shifts in weed communities are manageable, annual density fluctuations remain of minor significance for the farm economy. Long-term studies with integrated farming systems based on noninversion tillage did not result in increased weed-control intensity or costs. On the contrary, significant reductions in herbicide use and costs were achieved.[14,23] However, effective weed management requires tillage-adapted intervention, with herbicides as an integral part of the control strategy. The eradication of the last individual weed is not the goal but rather maintaining weed density below the economic threshold

or at manageable levels. Weeds within the tolerance levels may even contribute to ecosystem functioning, as they provide food sources for natural enemy species (parasitoids and predators of pests) and deflect the feeding pressure of initial pest infestations in crop stands, as shown, for example, for sugar beet crop.

Effects of tillage practices on crop seeds are mostly related to seed placement in seedbed, soil seed cover, and moisture supply. An imprecise seed placement in coulter-cut grooves during sowing leads to insufficient soil cover and scarcity in soil moisture supply. Retarded seed germination, longer exposure to soil-borne pests and pathogens, and poor crop establishment are the expected effects. Such constraints are believed to be more frequent under no-plow systems than under conventional tillage. Although more frequent, the problem can hardly be attributed to the tillage system rather than to the technical and operational quality of the drilling machines used. Deviations from the optimal sowing depth, placement in furrows, soil contact, and moisture supply are likely to cause seedling losses and poor crop stands. Modern direct drills and combination of cultivation and drills, as illustrated in Chapter 1, however, have successfully overcome such technical constraints. Crop establishment under no-tillage conditions is no longer the inferior drilling choice. By contrast, under dry cropping conditions or in semiarid areas, no-tillage and noninversion tillage options almost regularly achieve better crop establishment.

12.3.8 Pests and Diseases

A consideration of tillage effects on pests and diseases reveals a wide range of specific responses. Literature reviews[1,17,22,46] have considered all soil cultivation types including surface, shallow harrowing, tine cultivation, and moldboard plowing. Based on these reviews, it is impossible to determine trends regarding tillage impacts on pest species. Crop species and the spatial and temporal occurrence patterns of the pest species involved are considered to be as significant as tillage type or tillage intensity. Only with background details can the responses of given pest species be described. The inversion of soil by plowing exposes certain pests to weather conditions that may contribute to suppression of their populations.[1,37,46] Other species that resist soil structural changes may be temporarily affected but recover thereafter. Due to the large number of crops of interest in world agriculture and even larger number of pest species involved and variations of the climatic determinants, only two pest groups—slugs and single nematode species—are addressed in this book and are presented as examples. There is, however, a large inventory of published results on the effects of soil tillage on pest species. (see, for example, Reference 46). As with disease, only “soil-borne” species may directly interact with the tillage system, and immigrating species are often only indirectly influenced.

Strategies for tackling most insect pests under reduced-tillage regimes are outlined and are in various regions successfully managed. None of the common pest species tended to determine a particular tillage concept, despite higher infestation in single cases. Although manageable, slugs in humid temperate zones receive special attention since noninversion-tillage methods tend to have less effect in reducing slug populations than plowing. Avoidance of mechanical cultivations during seedbed preparation seems to improve slug survival considerably. On the other hand, some long-term

studies have shown substantial declines—assumed to be due to natural enemies—in slug populations on no-tillage plots following high slug populations. It is therefore important to adjust crop rotation to adversely affect prevailing slug species. Crop rotation, species, and variety can be complementary components in slug-control strategies. In contrast to no-tillage systems, noninversion tillage concepts may provide additional options with slug-suppressive effects, e.g., shallow harrowing.

The effects of cultivation practices on arable crop diseases also vary. The diseases most influenced by cultivation practices are either soil-borne or survive on previous crop residues. Some diseases were suppressed under conservation tillage, others enhanced. The significant disease-suppressing effects of crop rotation and variety selection place soil tillage at the fourth or fifth step in disease-control strategies. Crop rotation acquires particular significance when the pathogens concerned are difficult to control by chemical means, e.g., *Fusarium graminearum* in Germany. Banning host crop species with high pathogen carry-over potential, e.g., maize in winter-wheat-dominated crop rotations, thereby enhancing breakdown processes of maize crop residues, is likely to reduce infestation level in the following wheat crop.

12.3.9 Tillage and Off-Farm Implications

Agriculture is seen as the source of a number of environmental problems and, consequently, social ills.[6,21,40] Soil tillage is increasingly linked to runoff and soil erosion potential, which provoke additional expenses to nonfarming communities. Soil erosion, nonpoint pollution, and emissions of agrochemicals have become major concerns to society and governments. Contrasting no-tillage against both noninversion tillage and plowing with regard to soil losses, in particular at steeply sloping sites, convincingly demonstrates the soil-conservation benefits of the no-tillage approach. Direct drilling, in combination with adjusted crop rotation that maintains soil cover, is acknowledged to be the most effective management strategy in erosion control in arable farming. In studies, erosion rates declined significantly as tillage was reduced.

In many countries, chemical emissions to the environment and atmosphere are considered significant issues in national regulation. Research is addressing these issues intensively, aiming at risk assessments for gasoline, pesticide, and mineral fertilizer use in agriculture. In contrast to ground- and surface-water pollution, little data are available on the amount of agrochemicals released into either the atmosphere or stratosphere.

Based on the risk-assessment approach, average chemical consumption per unit area may support contrasting evaluations of the three main systems of soil management. Fuel consumption under no- and noninversion-tillage systems is significantly lower than with conventional plowing (see Chapter 1, and Reference 40). This reduces gaseous atmospheric pollution. Consequently, reduced tillage intensity contributes indirectly to minimization of global pollution related to the greenhouse effect.

Research results in different climatic regions show that no-plowing tillage enhances soil nutrient reserves.[9] Enhanced microbial activity, in particular mycorrhizae, under such tillage systems contributed to substantial improvements in soil phosphorus, carbon, and nitrogen reserves. Accordingly, the need for mineral fertilizers is likely to diminish. Compared to plowing, the risk of eutrophication declines,

together with CO_2- and N_x-oxide emissions. On the other hand, untilled soils exhibit higher water-flow rates with nitrate-leaching risk. As long as nitrogen supply is partitioned to match the uptake pattern of the plant species being grown, nitrate leaching remains at a minimum, as shown in studies in temperate climate zones.[14,23] Pesticide consumption under conservation tillage did not show a consistent relationship to tillage systems. Some studies referred to higher needs for herbicides or molluscicide treatments, mainly in monoculture or narrow rotations. The majority, in contrast, did not confirm specific trends. The long-term system comparisons in the UK and Germany[14,23] resulted in significant reductions in pesticide consumption, averaging 33–50% in total pesticides, herbicides (30–60%), fungicides (60%), and insecticides (>90%). Although this does not indicate the actual environmental pollution potential, it suggests minimized environmental pollution.

12.3.10 Carbon Sequestration and Humus Content

The most evident effect of tillage is documented for soil organic matter. Under comparable rotation there is a gradual increase of soil organic matter under minimum-tillage regimes. The highest humus content is found in no-tillage and the lowest in plowing systems. Moreover, the distribution pattern of organic matter in the soil profile matches very closely the concentration of soil biota, showing high levels in the topsoil and declining with depth. Carbon enrichment of unplowed soils indicates that the conservation of soil organic matter contributes to carbon sequestration and lower global warming impacts.[41]

12.4 CONCLUSIONS

Both no-tillage and noninversion tillage systems provide feasible soil-management options with less disturbance to soil agroecosystems compared to conventional plowing. The main objective of soil cultivation, i.e., the proper sowing and raising of crops, can be achieved at lower costs and labor hours. Apart from a few isolated exceptions, yield potential is not adversely affected, and the net farm revenue is improved. Observed constraints in crop emergence are mostly of a technical nature. Improvements in soil structure underscore the significance of conservation-tillage options to various trophic levels of soil biota for erosion control, soil fertility, and environmental safety. The relationships between soil tillage and the off-field environment comprise different kinds of interactions, including aboveground food webs, social costs, and landscape management.

Tillage-system-based shifts of soil biota tend to reflect increases in abundance, diversity, and functions as tillage intensity declines. Earthworms and various soil-inhabiting natural enemies demonstrated the most sensitive response to soil-management systems. Comparable responses to reduced tillage are identified for some annual and perennial weed species and slugs. Management of constraints is feasible, not necessarily at higher inputs or costs compared to conventional tillage systems.

The improved soil organic-matter content in no-plow soils categorize these tillage systems as supporting more sustainable agricultural resources that restrict environmental

as well as global pollution risk. Agroecosystems under no-plowing systems provide reliable strategies for ample combinations of sustaining the ecological functions, environmental safety, and economic interests of both farming and nonfarming communities. The modest concept that unifies these objectives is the integrated farming approach.[12,13]

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